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AP RECLAMATION AND REUSE IN RSRM PROPELLANT

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ABSTRACT

A solid propellant ingredient reclamation pilot plant has been evaluated at the Strategic Operations of Thiokol Corporation, located in Brigham City, Utah. The plant produces AP wet cake (95 percent AP, 5 percent water) for recycling at AP vendors. AP has been obtained from two standard propellant binder systems (PBAN and HTPB). Analytical work conducted at Thiokol indicates that the vendor-recrystallized AP meets Space Shuttle propellant specification requirements. Thiokol has processed 1-, 5-, and 600-gallon propellant mixes with the recrystallized AP. Processing, cast, cure, ballistic, mechanical, and safety properties have been evaluated. Phillips Laboratory static-test-fired 70-pound and 800-pound BATES motors. The data indicate that propellant processed with reclaimed AP has nominal properties.

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INTRODUCTION

In today's environment, recovery and beneficial reuse of hazardous waste materials is favored over destruction. Propellant and explosive manufacturers must treat day-to-day waste streams, and the government must treat overage and obsolete rocket motors. Thiokol has completed a two-phase cost sharing contract with the Joint Ordnance Commanders Group to reclaim ammonium perchlorate from composite Class 1.3 propellants, reprocess the material at AP vendors, and verify its reuse in rocket propellant. The first phase of the program, which has been reported previously,[1] involved recrystallizing the material through the

[1]Kathryn F. Miks, Thiokol Corporation, "Solid Propellant Ingredient Reclamation and Reuse," 1993 JANNAF Safety and Environmental Protection Subcommittee Meeting, Las Cruces, New Mexico.

Western Electrochemical Company's batch process and manufacturing subscale-size propellant mixes and test articles. The second phase of the program, which is reported herein, involved recrystallizing the material through the Kerr-McGee Chemical Corporation's continuous process and manufacturing a production-scale propellant mix and larger test articles.

OBJECTIVE

The objective of this program was to compare reclaimed AP with virgin AP in a baseline rocket propellant formulation.

SUMMARY

One hundred and fifty thousand pounds of AP wet cake were reclaimed from two standard propellant binder systems (PBAN and HTPB). The AP was recrystallized at the Kerr-McGee Chemical Company in order to obtain material of a specific particle size. Laboratory acceptance analyses and standard safety tests were performed on the recrystallized/reclaimed material. Twenty-one 1-gallon, ten 5-gallon, and one 600-gallon Space Shuttle propellant (TP-H1148) mixes were processed with the recrystallized/reclaimed AP. Rheological, cure, mechanical, ballistic, and safety properties were evaluated at Thiokol. Phillips Laboratory static-test-fired three 70-pound BATES motors and one 800-pound BATES motor.

CONCLUSIONS

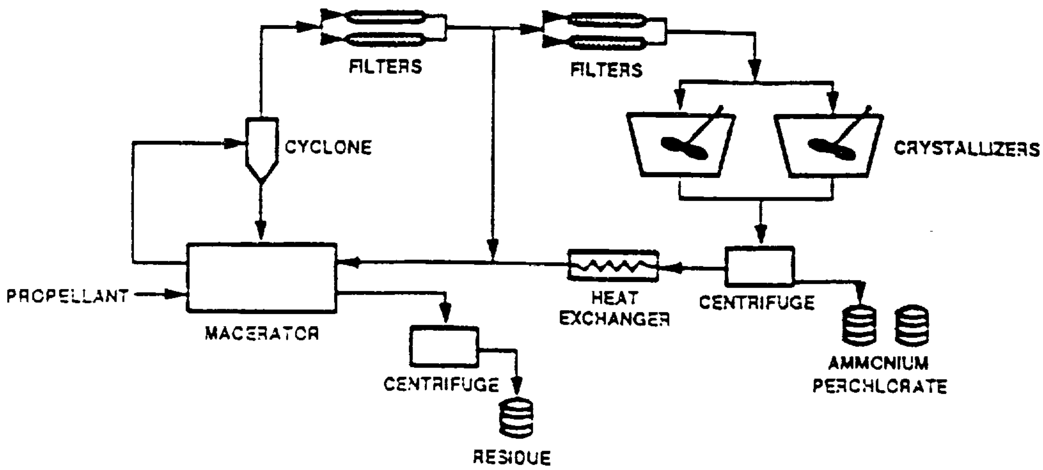
Reclaimed AP recrystallized at Kerr-McGee has nominal chemical, safety, friability, and grinding properties. Propellant processed with recrystallized/reclaimed AP has nominal rheological, mechanical, ballistic, and safety properties.

TECHNICAL DISCUSSION

DESCRIPTION OF PROCESS

A schematic of the reclamation process is presented below. A hydraulic macerator provides propellant size reduction and countercurrent extraction of the ammonium perchlorate at 160°F. The extract solution from the hydraulic macerator is passed through a liquid cyclone and an in-line filter to remove suspended solids before it is recirculated through the macerator. After the extract reaches a nominal 30 percent concentration, it passes through a second in-line filter and is cooled in two-stage batch crystallizers to precipitate the dissolved ammonium perchlorate. The recovered ammonium perchlorate crystals and the depleted propellant binder residue are dewatered in a basket centrifuge. The cold dilute filtrate from the crystallizers passes through a heat exchanger to pre-cool the next crystallizer batch before it is returned to the macerator for reuse.

AP Reclamation Process



AP RECOVERY

One hundred and fifty thousand pounds of AP wet cake were reclaimed over a 6-month period under a contract with Hill Air Force Base. Space Shuttle propellant (PBAN) comprised approximately two-thirds of the propellant feedstock, and Peacekeeper propellant (HTPB) comprised approximately one-third. The AP was integrated into the Kerr-McGee continuous process. Approximately 145,500 pounds of 50 percent reclaimed/50 percent virgin material were produced in a 4-day process run in 6 3/4 blend transient (BT) lots. One 21,000-pound BT lot, No. 99, was used in the subsequent evaluations.

AP ANALYSES

Space Shuttle specification acceptance analyses were performed on the recrystallized material and the results are presented in Table I. Specification requirements and nominal values for virgin Kerr-McGee material are also presented for comparison. Except for particle size, all of the recrystallized/reclaimed material values are within the specification requirements. The particle size data indicate that slightly smaller-than-nominal particles were obtained; a slightly lower-than-nominal percent of material is retained on the 70, 100, and 140 sieves. However, only the 100 and 140 sieves are below the specification requirement. BT Lot 99 was originally selected because analyses performed at Kerr-McGee showed that Lot 99 had a nominal particle size. The same analyses showed the remaining lots to be slightly large. Apparently, there was a bias between the Thiokol and Kerr-McGee analyses. Had a different lot been selected, it would have likely had a nominal particle size per Thiokol test methods.

In addition to the acceptance analyses, ion chromatography, inductively coupled plasma, gas chromatography/mass spectroscopy, nonvolatile organic, and Microtrac particle size analyses were performed. For comparison, the same analyses were run on virgin Kerr-McGee material. The results, presented in Table II, concur with the acceptance analyses that the reclaimed material is comparable chemically to virgin material, but the reclaimed AP has a slightly smaller particle size.

A friability evaluation was performed on two samples of reclaimed AP and on a control sample of virgin Kerr-McGee material. The test was performed using Rotap particle size analyses with 20 8-mm-diameter glass beads placed on each sieve. Particle size was determined initially without the glass beads (t = 0), and after vibrating with the beads for 15, 30, and 45 minutes. The data indicate that the rate at which particle size is reduced is similar for both reclaimed AP and virgin AP. After 45 minutes, the mean particle size of all samples was reduced by approximately 10 microns.

A grinding evaluation was performed with reclaimed AP and with virgin Kerr-McGee AP. Three grinds were made for each type of AP at the nominal settings determined for virgin AP target particle sizes of 5, 20, and 75 microns. Four composite samples from each grind were analyzed for particle size using Microtrac. The 75- and 20-micron grinds were completed with a 60 air classified mill, and the 5-micron grinds were completed with a 12-inch fluid energy mill. The data were analyzed using the student-t statistic at the 95 percent confidence level and indicate that reclaimed AP is comparable to virgin material and that acceptable particle sizes can be obtained per standard grinding methods.

Standard Thiokol safety tests were performed on the test material and on virgin Kerr-McGee material. Testing included: (1) Thiokol's tests for friction, impact, electrostatic sensitivity, and thermal stability; and (2) Allegheny Ballistics Laboratory's safety tests for friction and impact. Results are presented below. The values obtained for recrystallized/reclaimed AP were comparable to virgin Kerr-McGee material and indicate that the reclaimed AP presents no special shipping or handling problems over virgin 200-micron AP.

Test	Nominal Kerr-McGee AP 7229-0139	Recrystallized/Reclaimed AP 60000993-001
TC indirect impact (in.), 50%	44.0	43.2
ABL impact (cm), T.I.L.	21	21
TC strip friction (lb), 50%	>64	>64
ABL sliding friction, T.I.L.	560 at 8 ft/sec	660 at 8 ft/sec
TC ESD (Joules), 50%	>8	>8
Simulated bulk autoignition (onset exotherm)	402°F	410°F

ONE-GALLON PROPELLANT DEMONSTRATION

One-gallon Space Shuttle propellant mixes were made with the recrystallized/reclaimed AP. Three five-mix standardization matrices of TP-H1148 propellant were made using the same raw materials except for the AP. The five-mix matrix is used in Space Shuttle raw material evaluations to determine mechanical and ballistic property responses to HB/ECA and iron oxide levels, respectively. Five mixes were processed with 100 percent reclaimed AP, five mixes were processed with 100 percent virgin AP, and five mixes were processed with virgin AP in the unground fraction and reclaimed AP in the ground fraction.

Rheological, mechanical, and ballistic properties were determined from each mix. Standard Thiokol safety tests were performed on samples of uncured and cured propellant, and the results are presented below. All values were comparable to values for propellant processed with virgin AP. The initial 1-gallon data showed that acceptable rheological,

mechanical, ballistic, and safety properties could be achieved from propellant made with reclaimed AP.

UNCURED TP-H1148 PROPELLANT SAFETY PROPERTIES			
	Control (AB9570)	100% Reclaimed (AB9575)	Virgin Unground/ Reclaimed Ground (AB9580)
TC indirect impact (in.), 50%	13.3	15.6	14.5
ABL impact (cm), T.I.L.	41	26	80
TC strip friction (lbs), 50%	63.0	>64	>64
ABL sliding friction, T.I.L.	180 at 8 ft/sec	320 at 8 ft/sec	800 at 8 ft/sec
TC ESD (Joules), 50%	>8	>8	>8
TC confined ESD (Joules), 50%	8	8	8
Simulated bulk autoignition (onset exotherm)	365	363	372

CURED TP-H1148 PROPELLANT SAFETY PROPERTIES		
	Nominal	100% Reclaimed (2093116)
TC indirect impact (in.), 50%	12 - 14	18.5
ABL impact (cm), T.I.L.	11 - 13	33
TC strip friction (lbs), 50%	42 - >64	62.5
ABL sliding friction, T.I.L.	50 - 240	130 at 8 ft/sec
TC ESD (Joules), 50%	>8	>8
Simulated bulk auto ignition (onset exotherm)	340°F	360°F

Six additional 1-gallon propellant mixes were made to evaluate cast and cure properties. Two mixes each were made with 100 percent reclaimed AP, 100 percent virgin AP, and virgin AP in the unground fraction/ reclaimed AP in the ground fraction. Each mix was processed at the formulation determined for target mechanical properties, 110 psi maximum stress: 100 percent reclaimed AP mixes 86.9 percent PBAN polymer in the binder (HB), control AP mixes 86.9 percent HB, and virgin unground/reclaimed ground mixes 87.0 percent HB.

Cast properties were evaluated using a standard 1-gallon castability box. After 4 days' cure at 135°F, the height of each section was measured. The results indicate that casting properties for propellant made with reclaimed AP were comparable to the control and that propellant made with reclaimed AP has acceptable cast properties.

Cure properties were evaluated using propellant cast into 1- by 4- by 11-inch cartons. The cartons were cured at 135°F for 96, 120, 144, and 168 hours and postcured for 1 hour prior to testing. Mechanical properties were determined from four horizontal JANNAF Class C tensile specimens tested at 2 ipm, ambient temperature and pressure. Cure equations for maximum stress (σ_m), initial tangent modulus ($E^{2.6}$), and minimum strain at maximum stress ($\varepsilon_{\bar{m}}$) were determined from best fit regression analyses and are presented below.

Maximum Stress

(1) Virgin AP σ_m (psi) = -9.92 + 28.68 ln (time) $R^2 = 0.829$

(2) 100% reclaimed AP σ_m (psi) = -21.58 + 30.51 ln (time) $R^2 = 0.998$

(3) Mixed AP σ_m (psi) = 4.16 + 24.29 ln (time) $R^2 = 0.982$

Initial Tangent Modulus

(4) Virgin AP $E^{2.6}$ (psi) = -3.63 + 128.03 ln (time) $R^2 = 0.943$

(5) 100% reclaimed AP $E^{2.6}$ = 3.13 + 134.04 ln (time) $R^2 = 0.708$

(6) Mixed AP $E^{2.6}$ (psi) = 27.02 + 120.69 ln (time) $R^2 = 0.839$

Minimum Strain at Maximum Stress

(7) Virgin AP $\varepsilon_{\bar{m}}^{2.6}$ (%) = 71.90 - 5.53 ln (time) $R^2 = 0.890$

(8) 100% reclaimed AP $\varepsilon_{\bar{m}}^{2.6}$ (%) = 64.01 - 4.22 ln (time) $R^2 = 0.239$

(9) Mixed AP $\varepsilon_{\bar{m}}^{2.6}$ (%) = 82.59 - 7.89 ln (time) $R^2 = 0.851$

For the cure equations listed above, the slope controls the rate the propellant reaches its ultimate property. Although there are minor differences in cure rate between reclaimed AP propellant and the control, these differences are not alarming; similar differences in cure rate are observed between nominal Kerr-McGee and WECCO AP. Overall, the data indicate that acceptable mechanical properties can be obtained from propellant processed with reclaimed AP and cured per nominal propellant standards.

FIVE-GALLON EVALUATION

Five 5-gallon mixes of TP-H1148 propellant were processed with 100 percent reclaimed AP in accordance with the same matrix and raw materials as used in the 1-gallon evaluation. For comparison, five additional 5-gallon control mixes were processed at the same formulations with the same raw materials except virgin Kerr-McGee AP. The control mixes were completed as part of the Space Shuttle raw material standardization program.

End-of-mix (EOM) properties, which include total solids, percent ammonium perchlorate, percent aluminum plus ferric oxide, percent HB polymer, and liquid strand burn rate (LSBR) at 1500 psig and 100°F, were determined for each mix and indicate that acceptable propellant was processed. The LSBR regression equations are shown below.

(10) Virgin AP LSBR (in./s) = 0.4776 + 0.2375 (% Fe_2O_3) $R^2 = 0.990$

(11) 100% reclaimed AP LSBR (in./s) = 0.5006 + 0.2100 (% Fe_2O_3) $R^2 = 0.946$

The reclaimed AP propellant LSBR regression equation was compared to both the control and historical Space Shuttle regression equations (RSRM Flights 1 through 44). The reclaimed AP slope is comparable to the control at the 95 percent confidence level (student-t test) and falls well within the historical 3-sigma control limits. However, the intercept is statistically different from the control at the 95 percent confidence level (reclaimed AP has a slightly higher intercept). This may be due to the slightly smaller particle size of the

unground reclaimed AP. In any case, the predicted LSBR at 0.3 percent iron oxide is well within the historical 3-sigma control limits and indicates acceptable uncured ballistic properties. A plot of the comparisons is presented in Figure 1.

The end-of-mix (EOM) rheological properties, including EOM viscosity corrected to 145°F, Brookfield potlife at 135°F, and Haake viscosities for six shear rates at 135°F, were determined for each mix. Rheological properties help to characterize propellant flow and processability. The EOM viscosity and potlife values obtained for the reclaimed AP propellant were compared to both the control and to the historical database (RSRM Flights 1 through 39). The values are comparable to the control at the 95 percent confidence level (student-t test) and fall well within the historical 3-sigma control limits. Plots of the comparisons are presented in Figures 2 and 3. The data indicate that acceptable rheological properties can be achieved from propellant made with reclaimed AP.

Cured mechanical properties were determined from two half-gallon cartons cast from each mix. Cartons were cured for 96 ± 4 hours at 135°F and postcured for between 4 and 7 days prior to testing. The mechanical properties were determined from 12 JANNAF Class C tensile specimens tested at 2 ipm at ambient temperature and pressure. Regression equations for maximum stress (σ_m), initial modulus ($E^{2.6}$), and minimum strain at maximum stress ($\varepsilon_{\tilde{m}}$) as functions of HB polymer level are presented below.

<u>Maximum Stress</u>

(12) Virgin AP σ_m (psi) = 3976.8 - 44.64 (% HB) $R^2 = 0.999$

(13) 100% reclaimed AP σ_m (psi) = 3884.7 - 43.57 (% HB) $R^2 = 0.998$

<u>Initial Tangent Modulus</u>

(14) Virgin AP $E^{2.6}$ (psi) = 25,393.7 - 287.14 (% HB) $R^2 = 0.998$

(15) 100% reclaimed AP $E^{2.6}$ = 23,848.8 - 269.29 (% HB) $R^2 = 0.994$

<u>Minimum Strain at Maximum Stress</u>

(16) Virgin AP $\varepsilon_{\tilde{m}}$ (%) = -273.8 + 3.57 (% HB) $R^2 = 0.934$

(17) 100% reclaimed AP $\varepsilon_{\tilde{m}}$ (%) = -120.5 + 1.79 (% HB) $R^2 = 0.781$

The reclaimed AP propellant mechanical property regression equations were compared to both the control and historical (RSRM Flights 1 through 42) regression equations. The slope and intercepts are comparable to the control at the 95 percent confidence level (student-t test) and fall within the historical 3-sigma control limits. Nominal mechanical properties are predicted at 86.5 percent HB polymer. Plots of the comparisons are presented in Figures 4 through 6. The data indicate that acceptable mechanical property requirements can be achieved from propellant processed with reclaimed AP.

Cured ballistic properties were determined from three TU-131 motors (5-inch C.P. motors) cast from each mix and cured for 96 ± 4 hours at 135°F. The motors were tested at 625 psia and 60°F. The burn rate vs. iron oxide content regression equations are shown below.

(18) Virgin AP TU-131 R_b = 0.3338 + 0.1030 (% Fe_2O_3) $R^2 = 0.986$

(19) 100% reclaimed AP TU-131 R_b = 0.3429 + 0.1043 (% Fe_2O_3) $R^2 = 0.981$

The reclaimed AP propellant TU-131 regression equations were compared to both the control and historical (RSRM Flights 1 through 44) regression equations. The slope and intercept are comparable to the control at the 95 percent confidence level (student-t test) and fall within the historical 3-sigma control limits. Nominal ballistic properties are predicted at 0.3 percent iron oxide. A plot of the comparison is presented in Figure 7. The data indicate that acceptable ballistic property requirements can be achieved with propellant processed from reclaimed AP.

Five additional 5-gallon mixes were processed with reclaimed AP to standardize the raw materials used in the 600-gallon mix. The formulation determined to meet target mechanical and ballistic properties (110 psi maximum stress and 0.363 ips TU-131 burn rate at 625 psia, respectively) was 86.7 percent HB and 0.236 percent iron oxide.

FULL-SCALE EVALUATION

The 600-gallon mix was processed on January 6, 1994. The EOM viscosity was 14.5 kP at 144°F, and the Brookfield potlife to 40 kP at 135°F was 6.4 hours. Haake viscosities between 0.017 and 0.544 sec^{-1} shear rates were nominal for Space Shuttle propellant. End-of-mix acceptance properties, which include total solids, percent ammonium perchlorate, percent aluminum plus ferric oxide, and LSBR at 1500 psig and 100°F, were also determined to be nominal.

Mechanical properties were determined from 62 half-gallon loaf cartons cured at 135°F for 96 ± 4 hours. Standard quality assurance properties were determined from 12 JANNAF Class C tensile specimens tested at 2 ipm, ambient temperature and pressure. The results are presented below, along with the nominal values for Space Shuttle production (RSRM Flights 1 through 45). The data indicate that nominal TP-H1148 properties were obtained.

600-GALLON MIX QUALITY ASSURANCE MECHANICAL PROPERTIES

	Reclaimed AP Mix	RSRM Nominal (Flights 1-45)
Maximum stress, psi	117	112 (s = 5.9)
Minimum strain at maximum stress, %	35	36.5 (1.7)
Initial tangent modulus, psi	543	519 (52)
Strain at failure, %	44	48.7 (2.9)

Additional uniaxial characterization tests were performed at 25, 75, and 125°F, at ambient and 1000 psi pressure. Crosshead rates of between 0.02 and 20 ipm were used. Five JANNAF Class C tensile specimens were tested at each condition, and the results are presented in Table III. Failure envelopes were constructed at ambient and 1000 psi pressure and are shown in Figures 8 and 9, respectively. Historical TP-H1148 responses are also shown on each plot for comparison. The failure boundaries for propellant processed with reclaimed AP are well within the historical TP-H1148 propellant database and indicate that propellant processed with reclaimed AP has nominal failure parameters.

Stress relaxation tests were conducted at 25, 75, and 125°F, at ambient pressure. Five JANNAF Class A tensile specimens were tested at each temperature. The specimens were strained 5 percent at 250 ipm and the relaxation modulus, E_R, was determined between 0.1 and 1000 seconds. The master relaxation curve generated is shown in Figure 10, along with

historical TP-H1148 curves. The master curve is well within the historical TP-H1148 propellant database and indicates nominal material capabilities.

The propellant coefficient of linear thermal expansion (CLTE) was determined to be 6.06×10^{-5} in./in. ÷ °F. These results correlate well with the historical value of approximately 6.1×10^{-5} in./in. ÷ °F and indicate nominal CLTE properties.

The mechanical properties of propellant processed with reclaimed AP correlate very well to the historical TP-H1148 database. Quality assurance, variable rate/temperature uniaxial tests, stress relaxation, and CLTE analyses indicate that propellant processed with reclaimed AP has nominal material capabilities.

One 800-pound BATES motor, three 70-pound BATES motors, and twenty-two 5-inch C.P. motors (approximately 7 pounds) were fabricated for ballistic property evaluation. The 5-inch C.P. motors were tested at the Thiokol test facility between -35 and 135°F, and between 250 and 1000 psia. A summary of the results is presented in Table IV. The burn rate at 625 psia and 60°F is 0.365 in./sec. This is well within the RSRM historical 3-sigma control limits of 0.352 to 0.371 (RSRM Flights 1 through 45). The burn rate pressure relationship (n) was determined to be 0.312 from a logarithmic regression of the 16 motors tested at 60°F. This is comparable to the nominal TP-H1148 value of 0.311 at the 95 percent confidence level (student-t test). The pressure-temperature sensitivity (π_k) was determined to be 0.113 percent/°F from multivariant analyses of Motors 1 through 9. This correlates very well with the current TP-H1148 value of 0.11 percent/°F.

The data indicate that 5-inch C.P. ballistic properties of propellant processed with reclaimed AP correlate very well to the historical TP-H1148 database.

The three 70-pound BATES motors were static-tested at the Phillips Laboratory on Pad 5B. A summary of the results is presented in Table V. The results for each motor are from two independent pressure transducers. The first motor tested (347A-010) had an anomalous trace between about 1.25 and 2.25 seconds. An investigation concluded that both pressure transducer ports became blocked during testing, resulting in the anomalous trace. The remaining motors (347A-011 and 347A-012) had nominal traces and were used to calculate average performance.

Performance of the reclaimed AP propellant motors is compared to the historical 70-pound BATES baseline in Figures 11 through 13. An average burn rate of 0.442 ips at 958 psia was obtained for the reclaimed AP propellant motors, very near the target of 0.423 ips at 1000 psia. The reported and theoretical specific impulse of 294- and 316-lbs*sec/lb are well within the 3-sigma historical control limits, as is the resultant efficiency of 93.2 percent.

The 70-pound BATES data indicate that target properties were obtained and that ballistic properties of propellant processed with reclaimed AP correlate very well to the historical database.

The static test firing of the 800-pound BATES motor was also performed at the Phillips Laboratory. As with the 70-pound BATES motors, the pressure data were measured with two independent pressure transducers. The thrust measurement was obtained from the summation of three parallel load cells. The trace of the thrust data indicted an uncharacteristic ringing of the test stand at ignition. This ringing is a measurement anomaly and is not believed to be related to the propellant performance. However, since the ringing was large enough to shift the load cell readings, the thrust data are unreliable. Because motor efficiency is calculated from thrust data, efficiency values are also unreliable. This anomaly is being investigated so that the thrust data can be adjusted to show the true thrust

generated by the motor. The remaining data obtained from the motor firing were nominal. All results are presented in Table VI.

The values obtained from the 800-pound BATES firing compare very well to the 70-pound BATES data. The chamber pressure and burn rate for the motors are nearly identical. The measurements from the 800-pound motor firing indicate that the propellant processed from reclaimed AP has nominal propellant properties.

TABLE I
KERR-MCGEE RECRYSTALLIZED/RECYCLED AP ACCEPTANCE LABORATORY ANALYSES

Test	Reclaimed AP 60000993-0001	Kerr-McGee Nominal	RSRM Specification	
			Minimum	Maximum
Iron, as ferric oxide (%)	0.000	0.0003	--	0.0036
Chlorate, as ammonium chlorate (%)	0.00	0.005	--	0.02
Chloride, as ammonium chloride (%)	0.00	0.01	--	0.155
Phosphate, as tricalcium phosphate (%)	0.14	0.16	0.10	0.25
Bulk density (g/in.^{3})	19.1	18.9	18.0	
pH	5.9	6.4	5.0	6.6
Acid insolubles (%)	0.01	0.008	--	0.04
Bromate, as ammonium bromate (%)	0.000	0.000	--	0.004
Perchlorate, as ammonium perchlorate (%)	99.0	99.4	98.3	--
Sulfated ash, as sodium perchlorate (%)	0.4	0.3	--	0.9
Total moisture (%)	0.02	0.02	--	0.06
External moisture (%)	0.0	0.01	--	0.02
Internal moisture (%)	0.01	0.01	--	0.04
Particle size distribution, percent retained				
40 sieve	0	<1	0	1
50 sieve	8	8	6	11
70 sieve	35	39	33	43
100 sieve	64	70	66	76
140 sieve	87	91	88	95
200 sieve	98	98	97	100

TABLE II
KERR-MCGEE RECRYSTALLIZED/RECLAIMED AP CHARACTERIZATION ANALYSES

Stock-Lot		MDL	Reclaimed 60000993-1	Virgin 7229-0139
Anions:	Chloride (ppm)	25	ND	ND
	Sulfate (ppm)	30	41.6	64.6
	Nitrate (ppm)	30	107	117
Metals (ppm):	Al	2.50	ND	ND
	Sb	5.00	ND	ND
	Ar	5.00	ND	ND
	Ba	0.10	ND	ND
	Be	0.10	ND	ND
	Cd	0.30	ND	ND
	Ca	1.00	683	786
	Cr	0.50	ND	ND
	Co	0.30	ND	ND
	Cu	0.20	ND	ND
	Fe	0.50	ND	1.64
	Pb	2.50	ND	ND
	Mg	0.10	5.22	9.07
	Mn	0.10	0.22	0.22
	Hg	NA	NA	NA
	Mo		0.279	0.279
	Ni	1.00	ND	
	K	40.00	94.0	80.0
	Se	5.00	ND	ND
	Si		0.418	0.418
	Ag	0.30	ND	ND
	Na	1.0	31.2	45.1
	P		ND	ND
	Tl	5.00	ND	ND
	Sn	2.00	ND	ND
	V	0.20	ND	ND
	Zn	0.40	ND	0.86
Volatile organics (ppm)		1	ND	ND
Nonvolatile organics (ppm)		40	179	200
Particle size (μ):	10%		118	131
	50%		197	211
	90%		321	337

MDL = Method Detection Limit
ND = Not Detected
NA = Not Tested

TABLE III
KERR-MCGEE RECLAIMED/RECRYSTALLIZED AP TP-H1148 PROPELLANT UNIAXIAL TENSILE PROPERTIES

Temperature (°F)	Pressure (psi)	Rate (ipm)	$E^{2.6}$ (psi)	ε_{m+}^{t} (%)	ε_f^{t} (%)	σ_m (psi)	σ_m^{tc} (psi)	ε^{tc} (%)
25	Ambient	0.02	815	34.0	42.2	131	178	40.4
		0.2	1067	36.8	46.0	165	231	41.3
		2	1640	32.2	46.1	227	316	41.0
		20	2900	28.3	47.2	331	451	39.0
25	1000	0.02	1090	40.1	42.4	329	461	41.2
		0.2	1460	40.1	43.6	433	610	41.7
		2	2460	35.5	38.2	599	814	36.9
		20	3320	32.5	36.1	694	925	34.7
75	Ambient	0.02	555	27.7	31.3	93.7	121	31.4
		0.2	571	33.3	39.3	105	141	36.8
		2	726	36.7	48.2	126	176	43.3
		20	925	40.5	56.0	162	234	49.6
75	1000	0.02	690	34.2	35.6	181	243	34.9
		0.2	624	36.6	41.0	211	288	37.5
		2	930	38.3	46.5	254	356	42.2
		20	1090	45.4	63.3	338	501	53.8
125	Ambient	0.02	438	21.4	23.7	65.5	79.5	21.7
		0.2	447	25.3	29.6	74.7	94.3	27.4
		2	572	28.8	36.2	87.9	115	33.3
		20	661	33.8	45.6	111	153	41.5
125	1000	0.02	488	29.1	29.7	118	152	29.2
		0.2	610	32.1	33.7	145	191	32.0
		2	742	34.9	39.3	179	243	36.5
		20	830	40.2	56.2	232	331	45.4

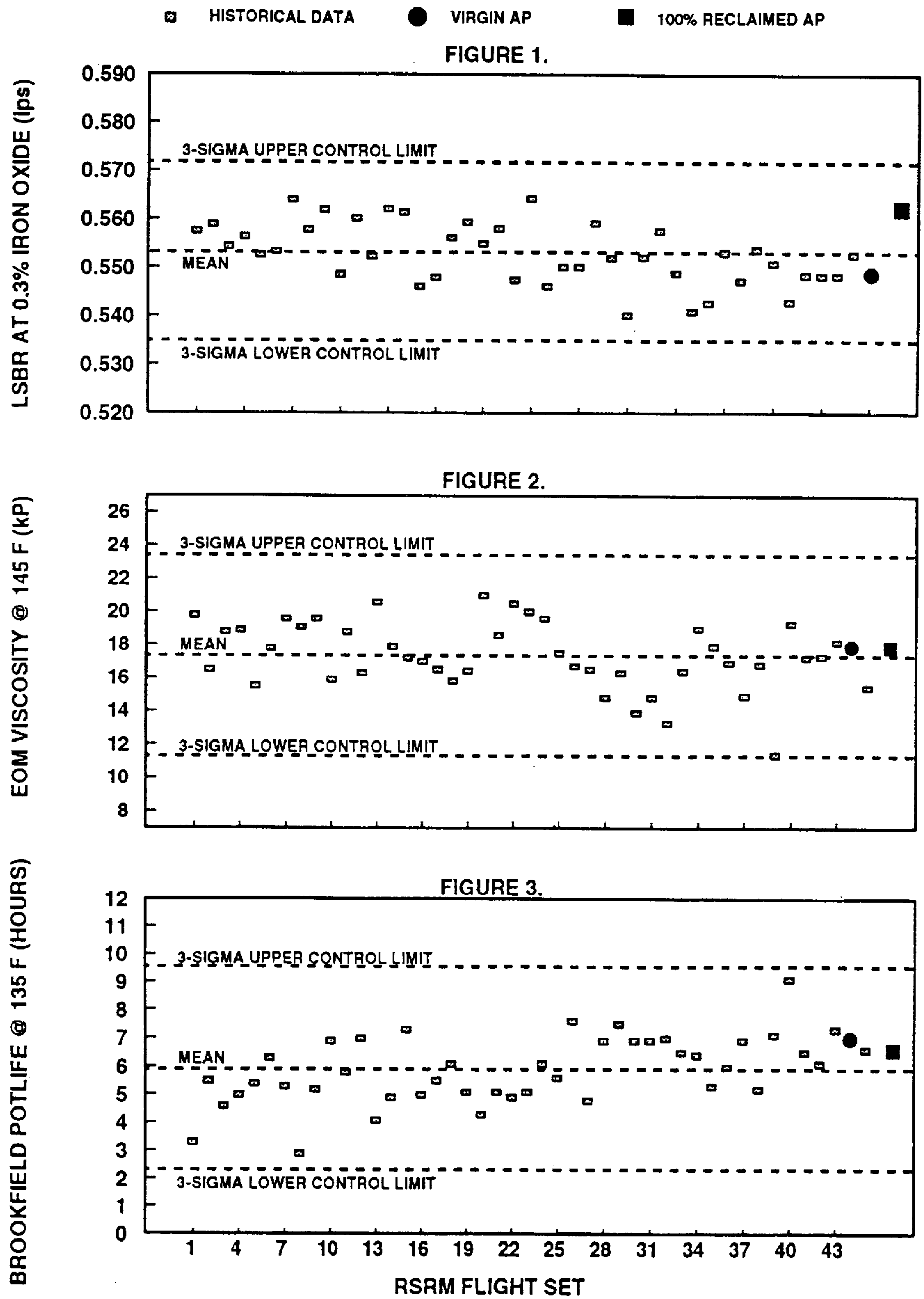
Values determined from five JANNAF Class C tensile specimens

TABLE IV KERR-MCGEE RECLAIMED/RECRYSTALLIZED AP TP-H1148 PROPELLANT 5-INCH C.P. MOTOR DATA SUMMARY			
Motor No.	Temperature (°F)	Pressure (psia)	Burn Rate (ips)
1	60	648	0.366
2	60	654	0.375
3	60	650	0.367
4	-35	591	0.341
5	-35	583	0.333
6	-35	584	0.335
7	135	711	0.403
8	135	707	0.400
9	135	711	0.402
10	60	240	0.267
11	60	242	0.272
12	60	239	0.271
13	60	502	0.338
14	60	502	0.340
15	60	508	0.343
16	60	782	0.393
17	60	764	0.387
18	60	765	0.389
19	60	1058	0.428
20	60	1056	0.429
21	60	1046	0.425
22	60	650	0.371

TABLE V RECLAIMED AP 70-POUND BATES BALLISTIC SUMMARY						
Firing No.:	347A-010	347A-010	347A-011	347A-011	347A-012	347A-012
Propellant weight (lbs)	73.83	73.83	73.78	73.78	73.40	73.40
Expansion ratio (A/A*)	9.952	9.952	9.966	9.966	10.337	10.337
Average pressure (psia)	872.2	869.5	949.7	945.2	971.3	967.7
Average thrust (lbs)	3898.08	3899.89	3835.96	3824.33	3971.32	3973.98
Action time (sec)	4.609	4.607	4.620	4.620	4.532	4.532
Burn rate average (ips)	0.451	0.451	0.429	0.429	0.455	0.455
Burn rate (ips at 1000 psia)	0.471	0.472	0.436	0.437	0.459	0.460
Delivered specific impulse (lbs*sec/lb)	243.343	243.352	243.259	243.252	245.179	245.242
Delivered specific impulse (vacuum)(lbs*sec/lb)	259.781	259.703	263.818	263.988	266.115	266.394
Report specific impulse (vacuum)(lbs*sec/lb)	296.022	296.122	293.505	293.619	295.103	295.418
Theoretical specific impulse (vacuum)(lbs*sec/lb)	316.018	316.018	316.018	316.018	316.018	316.018
Efficiency	93.672	93.704	92.876	92.912	93.352	93.491

TABLE VI RECLAIMED AP 800-LB BATES PRELIMINARY BALLISTIC SUMMARY		
Firing No.:	347L-001	347L-001
Propellant weight (lbs)	784.99	784.99
Expansion ratio (A/A*)	9.353	9.353
Average pressure (psia)	971.747	972.523
Average thrust (lbs)	29000.479	29040.432
Action time (sec)	6.190	6.191
Burn rate average (ips)	0.429	0.429
Burn rate (ips at 1000 psia)	0.433	0.433
Delivered specific impulse (lbs*sec/lb)	228.664	229.052
Delivered specific impulse (vacuum)(lbs*sec/lb)	246.873	247.276
Report specific impulse (vacuum)(lbs*sec/lb)	276.198	276.648
Theoretical specific impulse (vacuum)(lbs*sec/lb)	316.018	316.018
Efficiency	87.399	87.542

5-GALLON TP-H1148 UNCURED PROPELLANT PROPERTIES



K.F. MIKS 18 MAY 1994 JANNAF1.DRW

5-GALLON TP-H1148 PROPELLANT MECHANICAL PROPERTIES

HISTORICAL DATA ● VIRGIN AP ■ 100% RECLAIMED AP

FIGURE 4.

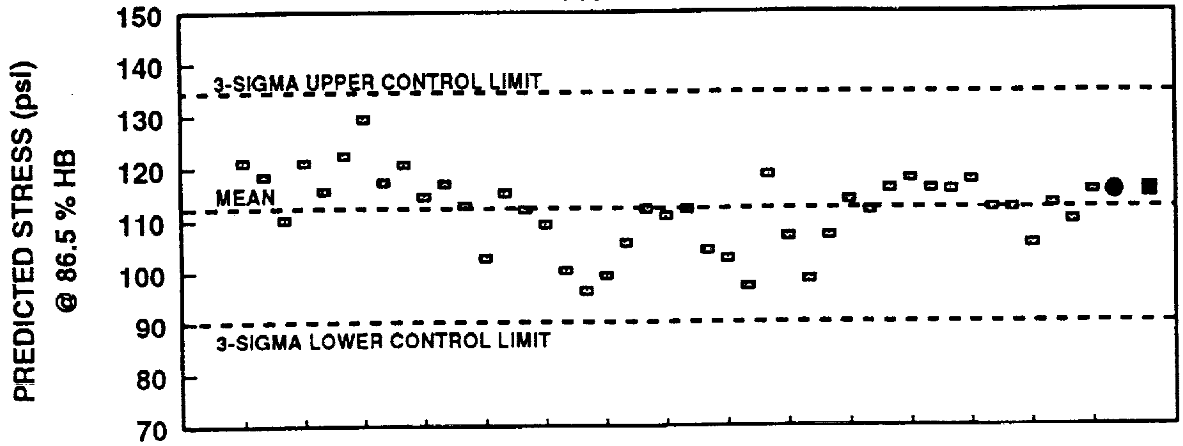


FIGURE 5.

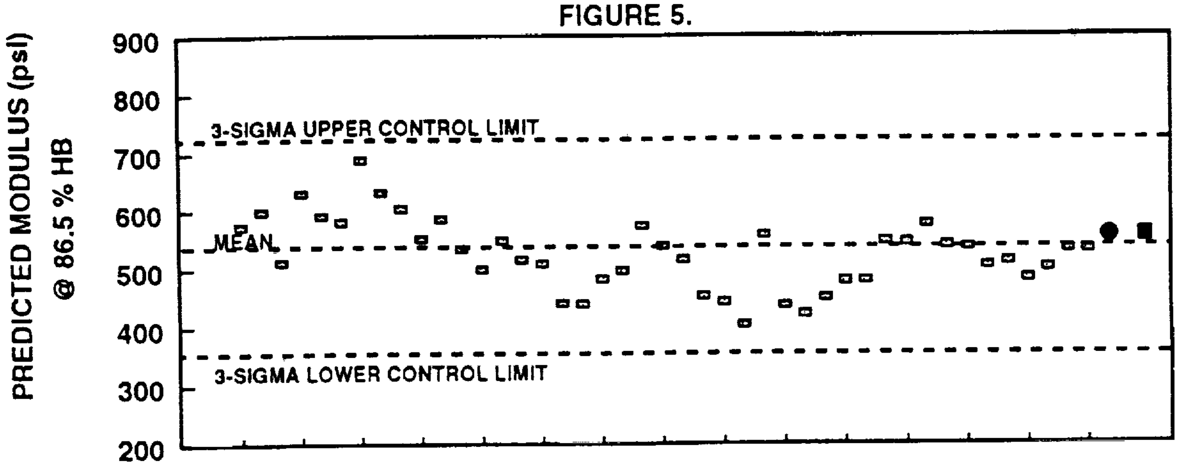
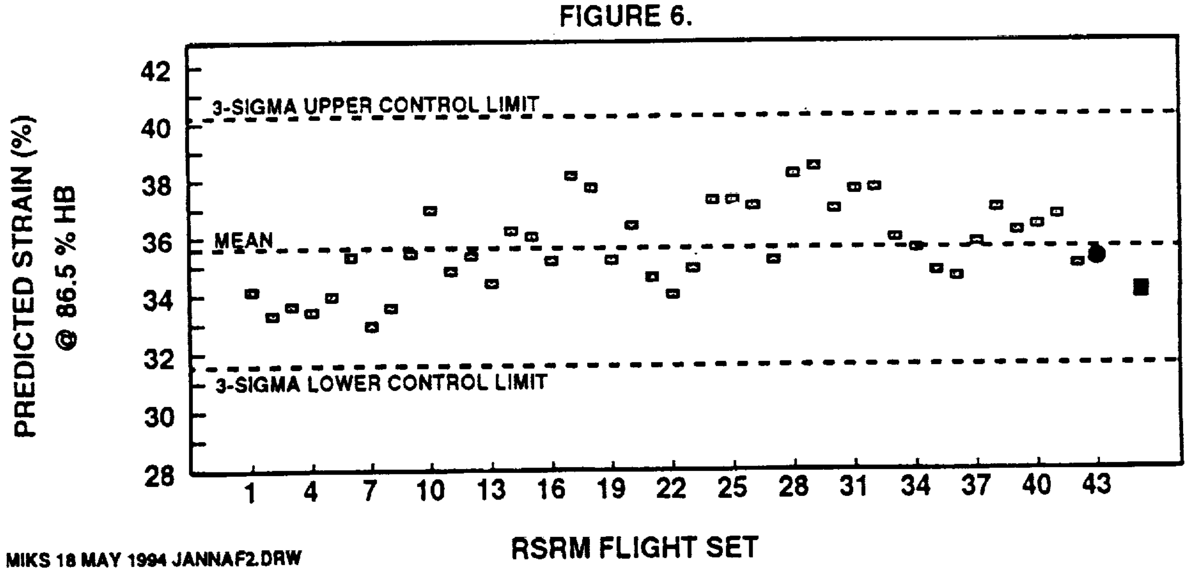


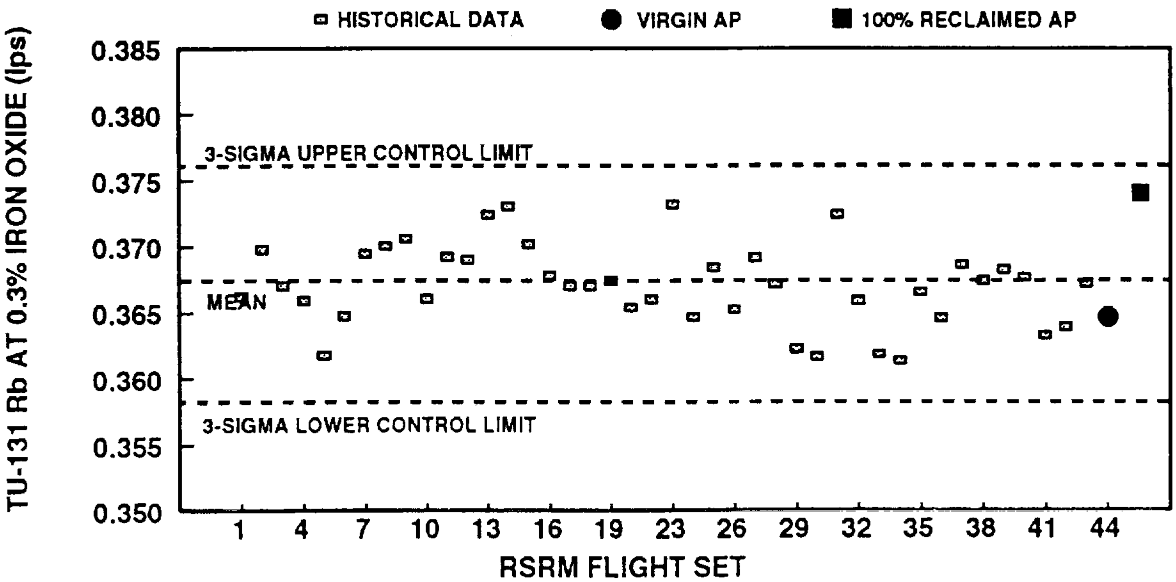
FIGURE 6.



K.F. MIKS 18 MAY 1994 JANNAF2.DRW

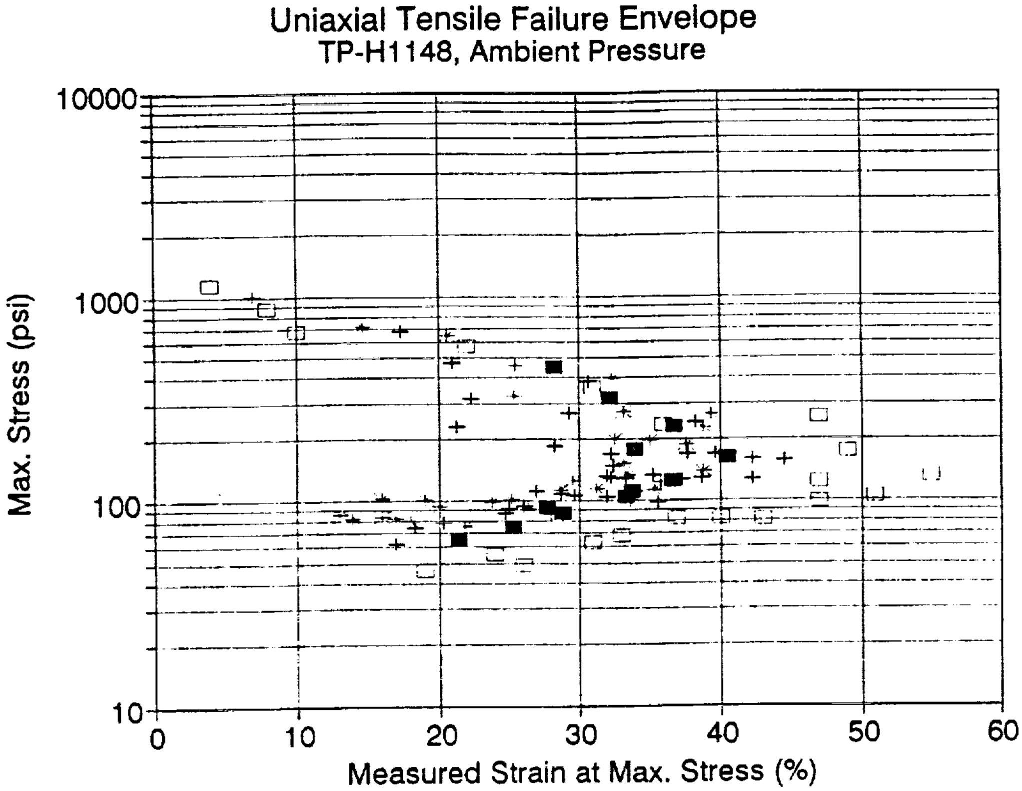
5-GALLON TP-H1148 PROPELLANT BALLISTIC PROPERTIES

FIGURE 7.



K.F. MIKS 19 MAY 1994 JANNAF3.DRW

Figure 8.



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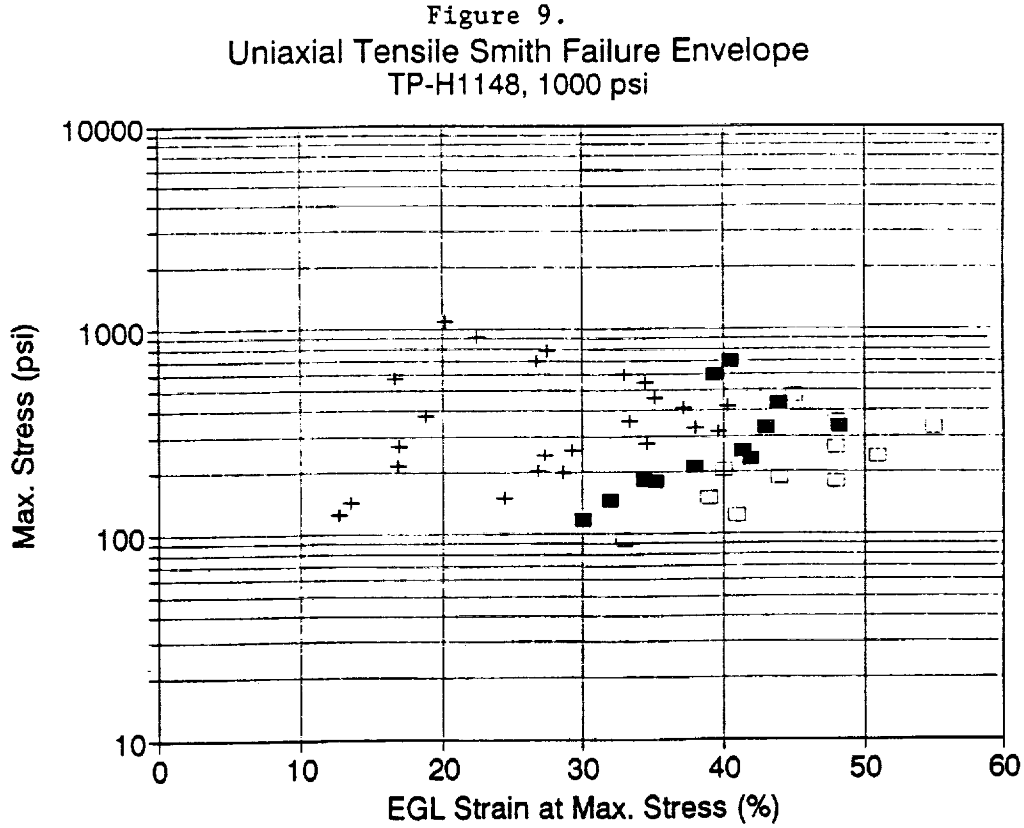
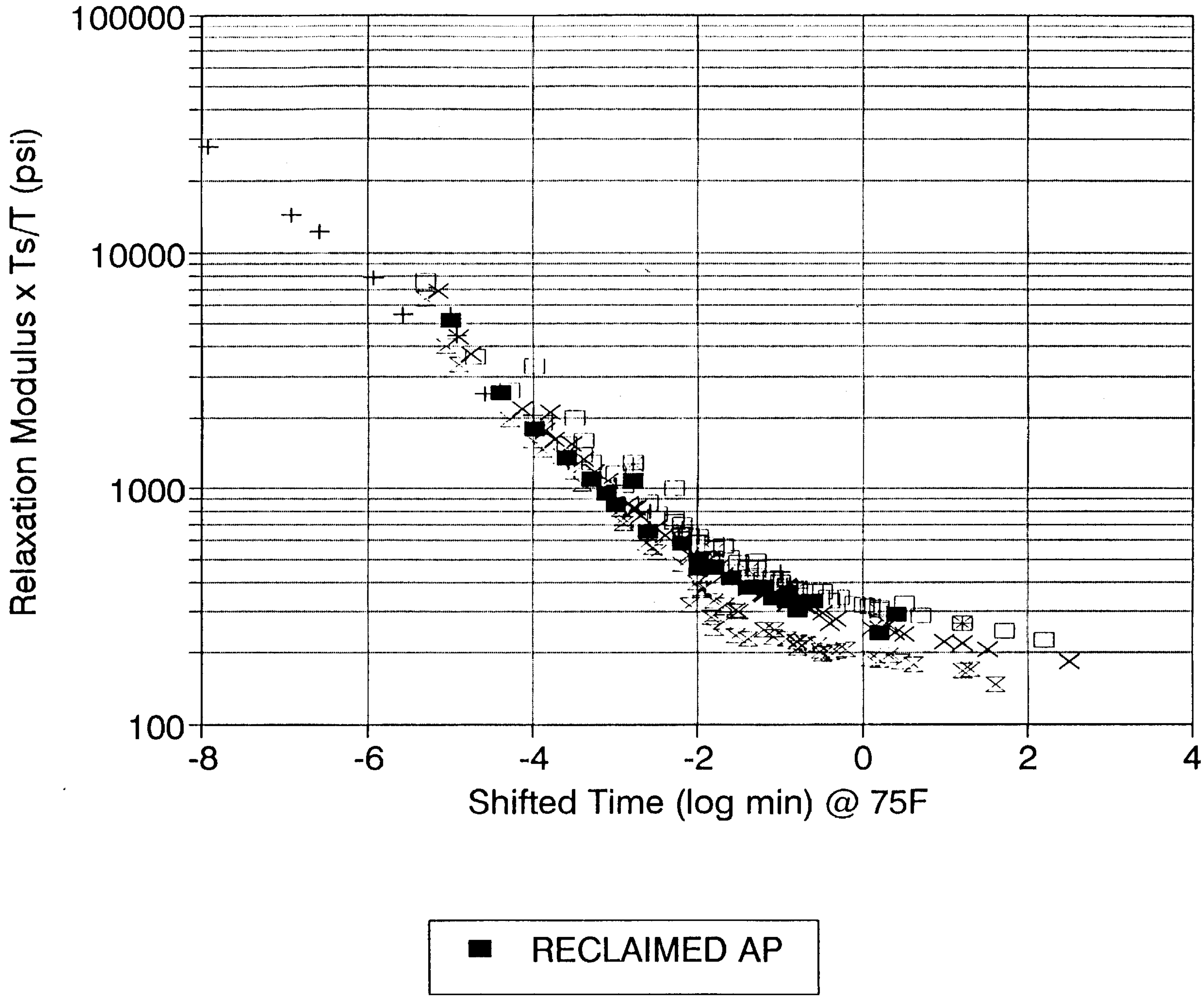


■ RECLAIMED AP

Figure 10.

Relaxation Modulus
TP-H1148



70-POUND BATES BALLISTIC PROPERTIES
TP-H1148 PROPELLANT

FIGURE 11.

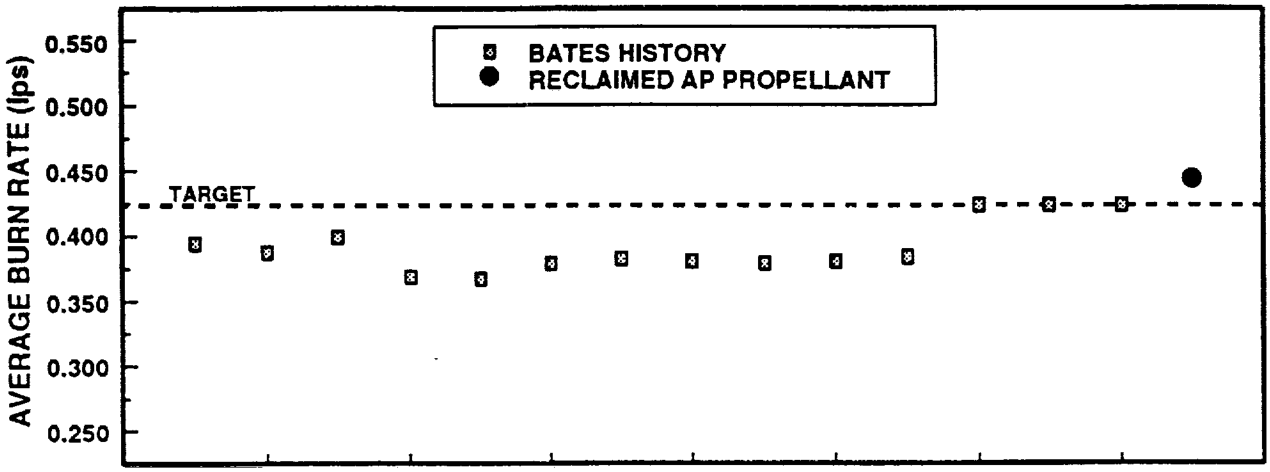


FIGURE 12.

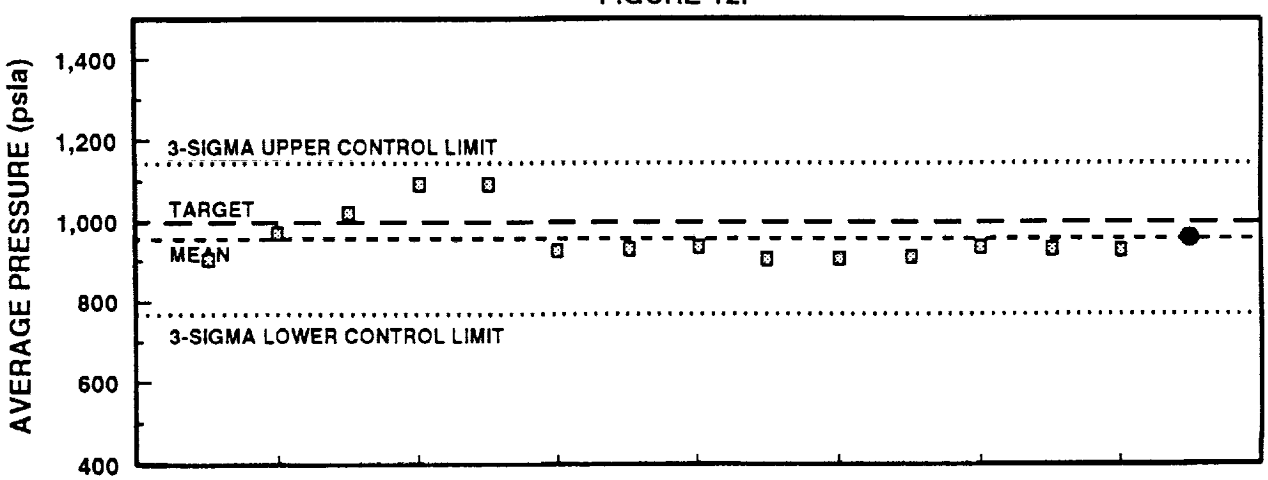
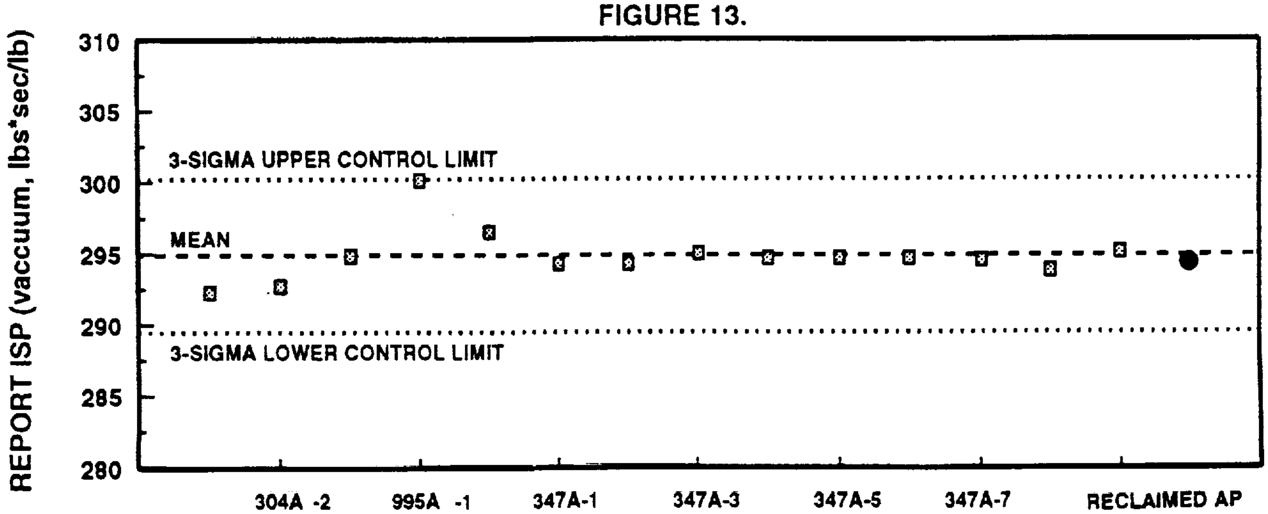


FIGURE 13.



K.F. MIKS 19 MAY 1994 JANNAF5.DRW